

DC-DC Boost Converter with Constant Output Voltage for Grid Connected Photovoltaic Application System

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Abstract

The main purpose of this paper is to introduce an approach to design a DC-DC boost converter with constant output voltage for grid connected photovoltaic application system. The boost converter is designed to step up a fluctuating solar panel voltage to a higher constant DC voltage. It uses voltage feedback to keep the output voltage constant. To do so, a microcontroller is used as the heart of the control system which it tracks and provides pulse-width-modulation signal to control power electronic device in boost converter. The boost converter will be able to direct couple with grid-tied inverter for grid connected photovoltaic system. Simulations were performed to describe the proposed design. Experimental works were carried out with the designed boost converter which has a power rating of 100 W and 24 V output voltage operated in continuous conduction mode at 20 kHz switching frequency. The test results show that the proposed design exhibits a good performance.

1. Introduction

Nowadays, power generation using solar power had increased dramatically because it is pollution free as compare to power generation using fossil fuel. Besides, it needs low maintenance and no noise and wear due to the absence of moving parts which make solar power attractive to the people. Solar power uses solar panel to convert sun irradiation into electric energy using photovoltaic (PV) effect. The output voltage of a solar panel is varying depending on sun irradiation and temperature [1]. As the sun irradiation and temperature changes, output voltage changing as well. Since the voltage produced is fluctuating, a lot of electronic equipments are unable to be directly connected. Therefore, a DC-DC boost converter with constant output voltage is needed. The boost converter will step up the solar panel voltage to the suitable voltage required by electronic equipments. For AC electrical equipments, the system requires an additional AC-DC inverter which converts the constant DC voltage to AC voltage. This system is called dual power processing stage system. Figure 1 shows a grid connected PV application system using dual power processing system. From the block diagram, the system does not use any batteries to store energy produced by solar panel. Any power produced by solar panel is directly deliver to the grid. Batteries are excluded from

the system because battery banks need high maintenance which had to be handled carefully in order to have a long lifetime and safe environment. Besides, batteries are the second major cost contributor for the system [2]. Therefore, the exclusion of batteries as the energy storage is economically advantageous [3].

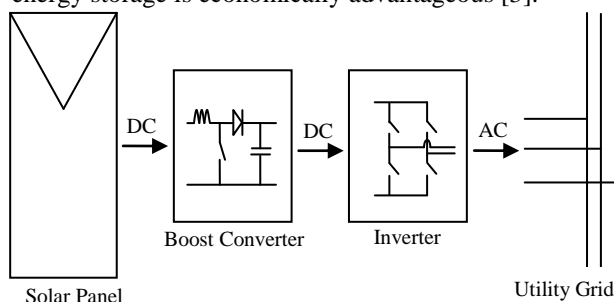


Figure 1. Block diagram of a grid connected PV application system.

2. Basic Operation

The boost converter is a medium of power transmission to perform energy absorption and injection from solar panel to grid-tied inverter. The process of energy absorption and injection in boost converter is performed by a combination of four components which are inductor, electronic switch, diode and output capacitor. The connection of a boost converter is shown in Figure 2 [4]. The process of energy absorption and injection will constitute a switching cycle [5]. In other word, the average output voltage is controlled by the switching on and off time duration. At constant switching frequency, adjusting the on and off duration of the switch is called pulse-width-modulation (PWM) switching. The switching duty cycle, k is defined as the ratio of the on duration to the switching time period. The energy absorption and injection with the relative length of switching period will operate the converter in two different modes known as continuous conduction mode (CCM) and discontinuous conduction mode (DCM) [4][6].

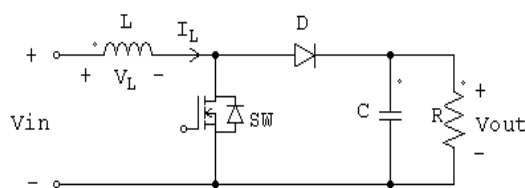


Figure 2. Schematic of boost converter.

3. Boost Converter Analysis

3.1. Continuous Conduction Mode

Under CCM, it is divided into two modes. Mode 1 begins when the switch SW is turned on at $t = 0$ as shown in Figure 3. The input current which rises flows through inductor L and switch SW. During this mode, energy is stored in the inductor and load is supplied by capacitor current. Mode 2 begins when the switch is turned off at $t = kT$. The current that was flowing through the switch would now flow through inductor L , diode D , output capacitor C , and load R as shown in Figure 4. The inductor current falls until the switch is turned on again in the next cycle. During this time, energy stored in the inductor is transferred to the load together with the input voltage. Therefore, the output voltage is greater than the input voltage and is expressed as

$$V_{out} = \frac{1}{1-k} V_{in} \quad (1)$$

where V_{out} is the output voltage, k is duty cycle, and V_{in} is input voltage [4].

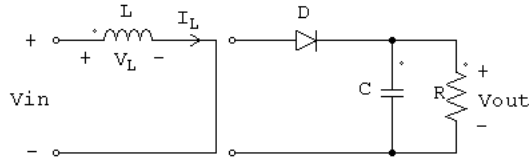


Figure 3. Circuit diagram of boost converter during Mode 1.

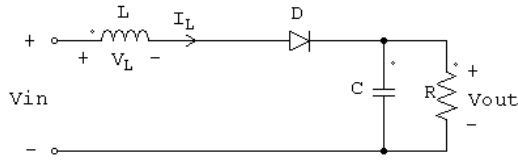


Figure 4. Circuit diagram of boost converter during Mode 2.

In order to operate the converter in CCM, the inductance is calculated such that the inductor current I_L flows continuously and never falls to zero as shown in Figure 5. Thus, L is given by

$$L_{min} = \frac{(1-k)^2 k R}{2f} \quad (2)$$

where L_{min} is the minimum inductance, R is output resistance, and f is the switching frequency of switch SW [4]. The output capacitance to give the desired output voltage ripple is given by

$$C_{min} = \frac{k}{R f V_r} \quad (3)$$

where C_{min} is the minimum capacitance and V_r is output voltage ripple factor [4]. V_r can be expressed as

$$V_r = \frac{\Delta V_{out}}{V_{out}} \quad (4)$$

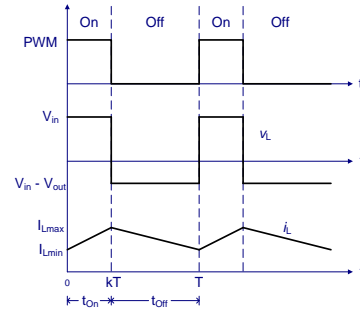


Figure 5. Boost converter waveforms at CCM.

3.2. Discontinuous Conduction Mode

Under DCM, inductor current I_L does not flow continuously. There is an interval of time which the current is zero before the next turn on of switch SW. The switching waveforms are shown in Figure 6. Taking integral of inductor voltage over one time period to zero,

$$V_{in} k T + (V_{in} - V_{out}) \Delta_1 T = 0$$

$$\therefore V_{out} = \frac{\Delta_1 + k}{\Delta_1} V_{in} \quad (5)$$

where T is switching period, Δ_1 is time period for negative inductor voltage and Δ_2 is time period for zero inductor voltage [4].

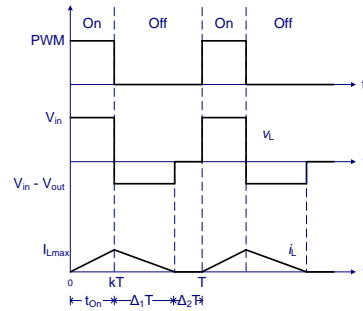


Figure 6. Boost converter waveforms at DCM.

As the value of L_{min} calculated previously is the minimum inductance to operate in CCM, therefore any values of L_{min} below than the minimum inductance will result in the boost converter to operate in DCM. The calculation for peak-to-peak ripple in the output voltage for DCM is the same as (3).

4. Proposed System

In this paper, a boost converter operated in CCM is designed to step up a fluctuating solar panel voltage to a higher constant output voltage of 24 V. Referring to [7], the range of the duty cycle is between 0 to 75% due to the instability cause by the parasitic components. The specification of the proposed design is shown in Table I.

TABLE I
SPECIFICATION OF PROPOSED BOOST CONVERTER

Mode	CCM
Power Rating (P)	100 W
Output Voltage (V_{out})	24 V
Output Current (I_{out})	4.2 A
Switching Frequency (f)	20 kHz
Input Voltage (V_{in})	6 – 23 V

In order to produce a constant output voltage, voltage feedback control system is used. In this control system, output voltage will be measured and compared with a reference voltage and the differential value is used to produce a PWM signal. Any changes in the output voltage will lead to the changes of duty cycle in PWM signal. To produce a set of PWM signal, a microcontroller is used. PIC16F877 microcontroller is selected as it is having a successive approximation analog-to-digital converter, comparator and PWM generator. PWM signal with frequency 20 kHz can be generated when PIC16F877 is driven by a 20 MHz clock cycle. Control strategy for voltage feedback control flow chart as shown in Figure 7 is written and load into PIC16F877 microcontroller.

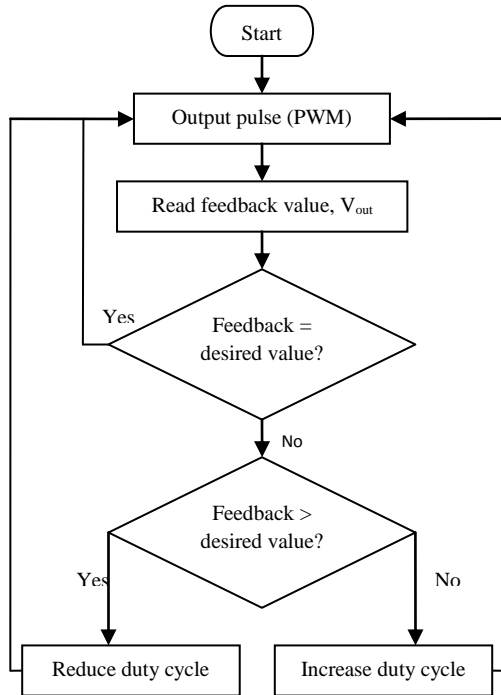


Figure 7. Control flow chart.

4.1. Selection of electronic switch

The electronic switch SW in Figure 2 has been chosen based on its voltage and current rating which have to be higher than the maximum input voltage and current. From the proposed system, the rating of the converter is 100 W with an input voltage ranging from 6 V to 23 V. Therefore, electronic switch such as power MOSFET, IGBT, BJT and thyristor handling capability should meet the specification of the proposed design.

4.2. Selection of inductor

Equation (2) is the minimum inductance for boost converter to operate in CCM, therefore the selection of the inductor should be higher than the calculated value. Inductors with a ferrite core or equivalent are recommended.

4.3. Selection of diode

Diode reverse voltage rating is the main consideration for selecting the diode. Other important consideration is its ability to block the required off-state voltage stress and have sufficient peak and average current handling capability, fast switching characteristics, low reverse-recovery, and low forward voltage drop.

4.4. Selection of capacitor

Equation (3) is the calculation for output voltage ripple using capacitance. The selection of capacitor should be higher than the calculated value to make sure that the converter's output voltage ripple stays within the specific range. Another important consideration is its equivalent series resistance (ESR). Since the capacitor's ESR affects efficiency, low-ESR capacitors will be used for best performance. ESR can be reduced by connecting few capacitors in parallel.

Table II shows the components used in the proposed design based on the equations and consideration mention previously.

TABLE II
BOOST CONVERTER CALCULATED PARAMETERS

Components	Value / Type
Electronic switch	IRF540N
Inductor	2.5 mH
Diode	MBR1060
Output capacitor	940 μ F
Load	5.76 Ω

5. Simulation and Experimental Results

5.1. Simulation results

Based on the proposed design, computer software PSIM is used to simulate the designed boost converter's performance. The simulation results of the boost converter with different input voltages and duty cycles are shown in Figure 8 and Figure 9.

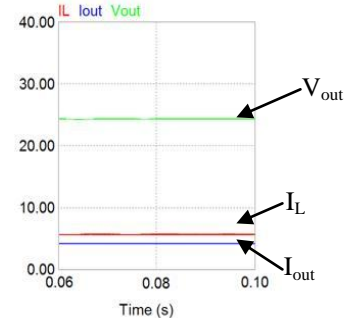


Figure 8. Simulation waveforms for output voltage, output current and inductor current at 25% duty cycle.

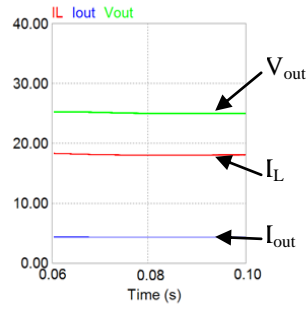


Figure 9. Simulation waveforms for output voltage, output current and inductor current at 75% duty cycle.

From the simulation results, the proposed converter is able to give a constant 24 V output voltage at 100 W loads.

5.2. Experimental results

Experimental measurements are being carried out in order to verify the performance of the boost converter proposed. A power supply is connected to V_{in} and a load resistance is connected to V_{out} as shown in Figure 2. Figure 10 shows the experimental results for different input voltages.

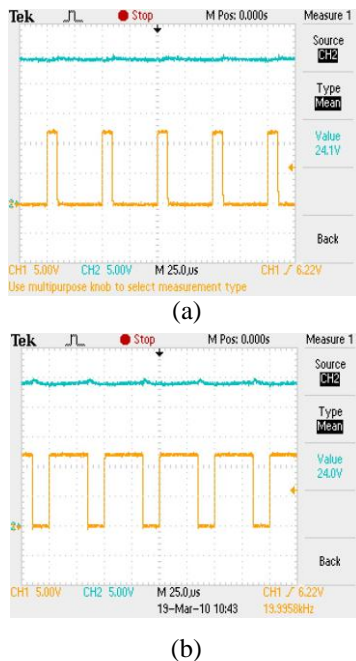


Figure 10. Output voltage waveform and PWM signal from PIC16F877 (a) with 19 V input voltage and 20% duty cycle (b) with 7 V input voltage and 70% duty cycle.

From the experimental results, it shows that the proposed design is able to produce a constant 24 V output voltage with a duty cycle of 70% and 20%. Table III shows the experimental results for the proposed boost converter whereas Figure 11 shows the efficiency of the boost converter for different loads.

TABLE III
BOOST CONVERTER EXPERIMENTAL RESULTS

Input voltage (V)	Input Current (A)	Duty cycle	Output Voltage (V)	Eff. (%)
23	4.57	0.04	24.1	95.1
15	8.23	0.38	24.0	81.0

The efficiency of the boost converter is calculated by the ratio of output power to input power. Efficiency can be increase by reducing the total losses of the converter. The losses in a boost converter consists of switching loss, conduction loss, inductor's eddy current and hysteresis loss, ESR and electromagnetic interference. Soft switching such as zero-voltage and zero-current switching is able to reduce switching losses in a boost converter.

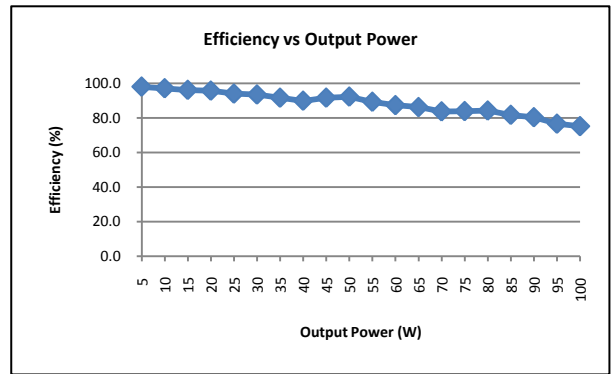


Figure 11. Efficiency versus output power for boost converter.

6. Conclusion

From the proposed design, the boost converter is able to produce a constant output voltage of 24 V from a variable voltage of solar panel. The boost converter is able to deliver power with the highest efficiency of 95%. Components had been chosen based on the consideration made. PIC16F877 microcontroller is able to perform the voltage feedback control technique.

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